MICRO-ALGAE OF LAKE PUPUKE, AUCKLAND, NEW ZEALAND

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ABSTRACT

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On the basis of its algal populations Lake Pupuke is classed as eutrophic. Over a period of 11 years, from 1976 to 1987, 96 taxa were identified in 102 algal samples obtained from mid-lake and inshore phytoplankton and phytobenthos, including metaphyton and epiphyton. The composition of the algal communities is discussed briefly in relation to seasonal changes, depth and water quality.

KEY WORDS: micro-algae - phytoplankton - phytobenthos - pollution - toxicity.

INTRODUCTION

The aim of this paper is to document the micro-algae in Lake Pupuke, North Shore, Auckland, from mid-lake and inshore phytoplankton, from communities growing in and around macrophytes (metaphyton, epiphyton), and from those on stony and muddy surfaces (epilithon, epipelon). Inshore sampling was qualitative rather than quantitative, and therefore estimates of abundance in Appendix I are subjective. Some quantitative counts have been made of mid-lake phytoplankton, from samples collected by officers of the Auckland Regional Authority. An assessment has been made of the trophic status of the lake from the species composition of algal communities.

HISTORY

Last century Hochstetter (1867) published a graphic description of Lake Pupuke as it was in 1857. More recent and precise accounts are those by Searle (1964), Barker (1966, 1967, 1970), Green (1967), Reid (unpublished 1976), the Auckland Regional Water Board (A.R.W.B.) (1978, 1979, 1983) and Coffey & Clayton (1987). Bathymetric contours (after Barker 1970) are indicated in Fig. 1.

A warm monomictic lake, Pupuke contains a volume of about 3 x 10^7 m^3 of fresh to brackish water. The concentrations of some ions are high, sometimes resembling those of seawater rather than freshwater. High pH values could be due to dominance of sodium bicarbonate (Barker 1970). Technically a maar, the lake occupies the crater basin of a tuff cone about 42,000 years old (Searle 1964), and has a mean depth of 34m below sea level (Barker 1970). Basaltic dykes occupy the inner crater walls and form vertical cliffs. Today the lake is widely used for recreational purposes.

Lake Pupuke was used as the North Shore's water supply from 1895. By 1924 it proved to be inadequate, many houses discharging sewage directly into the lake. High ammonia and sulfide values were recorded between 1925 and 1940 by the Government Analyst. Large amounts of oil contaminating the water supply, as well as taste and odour problems associated with the dinoflagellate *Ceratium hirundinella*, prompted the authorities in 1933, 1934 and 1938 to use large doses of copper sulfate to control noxious algal blooms. Chlorine and activated charcoal were also added to the lake. After construction of the pipeline over the Auckland Harbour Bridge, the lake was no longer used as the North Shore's water supply. Today, 46% of the catchment is zoned as residential, 28% commercial, 16% recreational, 8% for roading and 2% industrial (A.R.W.B. 1979).

Over the past 50 years there has been a considerable increase in eutrophication, with in-

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creasing urbanisation and consequent run-off of storm water, mixed in later years with a certain amount of sewage, due to failure of the pumping stations after heavy rainfall. In about December 1976, local residents and others became concerned for the lake's welfare and its value as a recreational resource. In response to an appeal from the Auckland Regional Authority, a preliminary report was prepared by the author in 1978 (A.R.W.B. 1979). In 1982, a Lake Pupuke Management Committee was formed, under the auspices of the Takapuna City Council, and as a result the sewage pumping stations were upgraded and large amounts of decaying lakeweed were mechanically removed.

The Auckland Regional Water Board has continued to monitor water quality and mid-lake phytoplankton, since the lake may be needed for water supply in the future. MAFFISH scientists from Ruakura Soil and Plant Research Station have conducted intensive diving surveys of the submerged macrophyte vegetation (Coffey & Clayton 1987).

As yet, however, there has been no comprehensive account of the algal vegetation of the lake. Taxonomic descriptions of the 33 commonest species will be presented in another paper. Algae have precise requirements for growth, and if correctly identified, can be used as indicators of trophic status and the degree of organic pollution (Cassie 1979).

MATERIALS AND METHODS

A total of 97 samples of phytoplankton, metaphyton, epilithon and epipelon were obtained at different seasons from 1976 to 1984, and a further 5 were examined after a follow-up visit in May 1987 (see Fig. 1). Methods used were:

a) net tows off jetties (inshore phytoplankton)
b) Van Dorn samplers (mid-lake phytoplankton), at depths of 0, 5, 10, 20, 30 and 50m, and

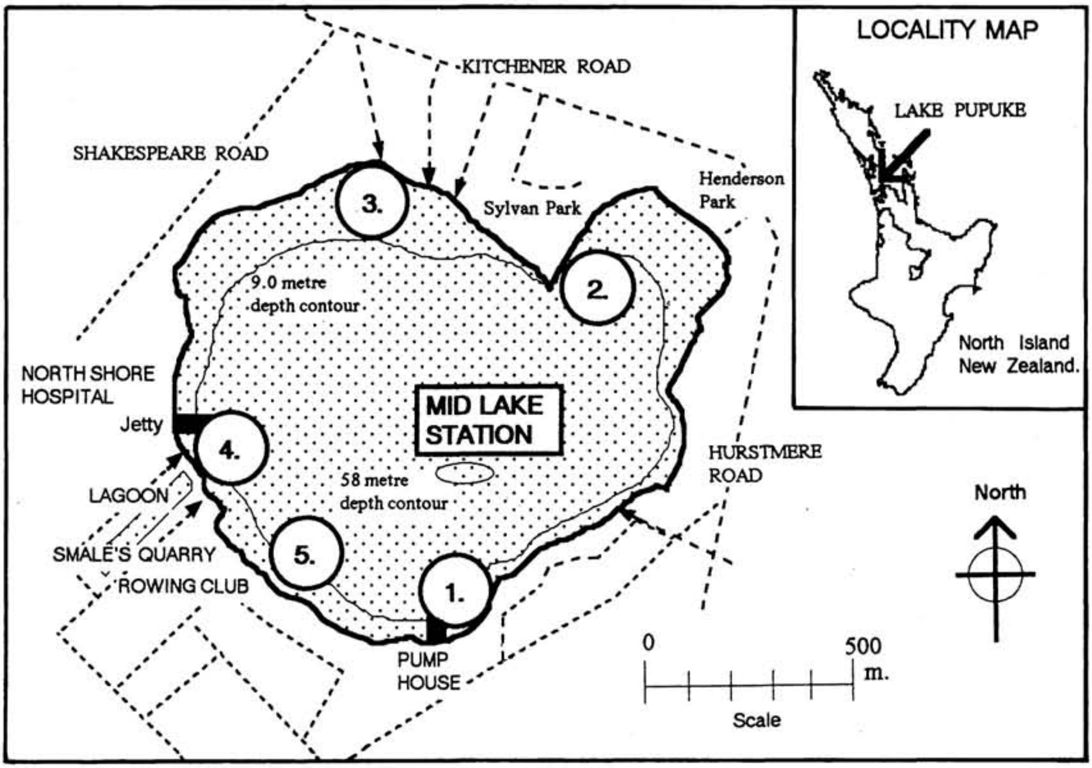

Figure 1. Sketch map of Lake Pupuke showing the locations of sampling sites. (After Coffey (unpublished) and Irwin (pers. comm.)).

c) 30-50ml bottle samples from:

1) below the pumphouse, Killarney Street;
2) Sylvan Park, by the boat ramp and under trees;
3) northern backwaters at 68 Shakespeare Road;
4) below North Shore Hospital, near the outlet of the main hospital stormwater drain; and
5) the lagoon at Smale's Quarry (metaphyton, epilithon and epipelon).

Fresh samples were transported to the Mt Albert Research Centre laboratory and examined under a Zeiss Universal light microscope equipped with phase and differential interference contrast objectives and semi-automatic camera attachments (V.C. Films 47, 48, 57). Some of the diatoms were investigated in greater detail under the SEM and TEM (V.C. photographic collection 94, 625-642). Representative samples were preserved in FAA and 5% formalin (Herb. Nos. 4b, 28-31, 35, 39, 43, 53, 55, 58, 59, 64, 67, 92, 2011, 2035-6, 2058, 2069, 2527-9, 2531-2, 2671, 2883, 3270). Algal taxa are recorded on dated drawing sheets. Preserved samples, slides, photomicrographs and drawings will shortly be deposited in the CHR Herbarium of Botany Division, DSIR, Christchurch.

RESULTS

Ninety six micro-algal taxa have been identified from Lake Pupuke (Appendix I, Table 1). Green algae, dinoflagellates and both centric and pennate diatoms were the most widely represented groups among the phytoplankton, while pennate diatoms and blue-green algae were most conspicuous in the metaphyton and epiphyton. Algae on mud (epipelon) and stone surfaces (epilithon) were probably more diverse than figures suggest, since these habitats were sampled only sporadically.

MID-LAKE PHYTOPLANKTON

As in previous records (Barker unpublished 1967, Green 1967), the desmids *Closterium aciculare* and *Staurastrum* spp. (*S. chaetoceras, S. muticum, S. pingue, S. johnsonii* and *S. smithii* f. *triradiatum*), dominated in winter and spring in the epilimnion. Also abundant were the three-horned dinoflagellate *Ceratium hirundinella,* cylindrical filaments of the centric diatom *Melosira granulata* and ribbon-like chains of the araphid pennate diatom *Fragilaria crotonensis*. In summer, principal species were blackish-blue-green colonies of *Microcystis aeruginosa*, and motile cells of *Peridinium* spp. (*P. volzii* and *P. willei*). Excystment of *P. volzii* was observed in February 1976 (Herb. 48) and in August 1983 (V.C. film 57). *Anabaena circinalis* and *Volvox* sp., recorded by Barker (1966), were not observed.

Counts were made by the author in April 1976 from mid-lake samples collected at depths of 0, 5, 10, 15, 20, 35 and 50m (Table 2). These

Class	Total no. of taxa	Metaphyton, Epiphyton	Phytoplankton	Benthos (Epipelon, Epilithon)
Chlorophyceae	36	10	23	3
Diatomophyceae				
a) Centrales	4	-	4	-
b) Pennales	26	19	1	6
Cyanophyceae	16	9	5	2
Euglenophyceae	5	3	1	1
Dinophyceae	4	1	3	-
Chrysophyceae	3	1	2	-
Cryptophyceae	1	-	1	-
Xanthophyceae	1	1	-	-

Table 1. Distribution of algal classes among different communities.

Depth	Date	No. of living species	Total cells/l	Dominants	Dominants' cells/l
0 m	23-4-76	14	$1.7x10^6$	*Closterium*	$1.4x10^6$
				Staurastrum	
	8-3-82	10	$1.5x10^7$	*Microcystis**	$9.5x10^6$
				Cystodinium	$9.0x10^5$
				Chroomonas	$4.0x10^5$
				Fragilaria	$3.0x10^5$
10 m	27-4-76	10	$1.9x10^6$	*Closterium*	$1.2x10^6$
				Staurastrum	$8.0x10^4$
	8-3-82	10	$1.6x10^6$	*Microcystis*	$1.4x10^6$
				Cystodinium	$8.0x10^5$
				Chroomonas	$3.0x10^5$
				Fragilaria	$2.0x10^5$
20 m	27-4-76	7	$1.1x10^6$	*Closterium*	$1.0x10^6$
				Staurastrum	-
	8-3-82	3	$8.0x10^5$	*Microcystis*	$5.2x10^5$

Table 2. Representative counts from autumn mid-lake phytoplankton samples of Lake Pupuke. Data for 8-3-82 from A.R.W.B 1983. * = present in colonies.

are compared with counts from similar depths made 5 years later in March 1982 by L. Ronberg (ARWB 1983). Results from both series indicate clearly that the bulk of the mid-lake phytoplankton was confined at the time of sampling to the upper 10-15 m. More recent unpublished counts also show a dramatic decrease below 20-28 m (E.T Grogan, ARWB, Pers. comm.) No dramatic change occurred between the surface and 15 m; but cell numbers decreased markedly below this. (The thermocline was located between 17 and 19 m on 27 April 1976; H. Ellis, pers. comm.).

In summer months, *Melosira* filaments are known to sink to the bottom of the lake, where they remain in the resting stage, to be returned to the photic zone with the onset of the winter overturn (Kilham & Kilham 1975). The April samples indicated that a winter phytoplankton community (*Closterium aciculare, Staurastrum, Fragilaria* and *Chodatella* spp.) was already dominant; whereas in early March samples, summer species (*Microcystis, Fragilaria, Cystodinium,* and *Chroomonas minuta*) still prevailed. Other seasonal variations are apparent in the more comprehensive surveys published by the Auckland Regional Water Board (1983).

INSHORE PHYTOPLANKTON

On the whole, the composition of inshore phytoplankton did not vary greatly from that in the main body of the lake. However, a distinctive community existed under the shade of willows and poplars in a backwater at Sylvan Park, where in November 1981 the shallows were discoloured by *Chlamydomonas, Euglena, Cystodinium*, *Oedogonium* sp. and the pennate diatom *Hantzchia amphioxys* - a eutrophic to polluted assemblage which reflected the increase of nutrients supplied from the break-down of abundant excreta from black swans. These used to congregate on the adjacent sheltered grassy banks, but now the banks are cemented in by a sloping stone wall. In May 1987, the algae had virtually disappeared from the backwater, and epilithic algae were absent.

Stagnant inshore waters south of the hospital harboured a new microalgal genus; *Kermatia pupukensis.* This species was described ultrastructurally by Dempsey *et al.* (1980) as *Chlorella minutissima* but was later recognised and named as a new taxon by Kalina & Puncochárová (1987). Its name is derived from "kermata", which means "a small coin" in Old Greek.

PERIPHYTON

Between 1976 and 1982, a persistent nuisance was created by huge rafts of floating *Vallisneria spiralis* L. which were dislodged by storms or torn off by swans for food or nests. In various stages of decay the rafts had drifted inshore, especially in northern and eastern parts of the lake. Up to 10 m in horizontal extent, these rafts were solid enough for birds to walk on; and provided an ideal habitat for many microalgae on the upper surface of their canopy, as well as for bacterial and colourless flagellates beneath the decaying surface. Upper faces of *Vallisneria* leaves supported a wealth of pennate diatoms, notably *Cocconeis placentula, Epithemia sorex, Synedra ulna, Rhopalodia* sp., and flat discs of the chaetophoralean green alga *Coleochaete orbicularis*. Periphytic filamentous forms growing on *Cladophora glomerata* (L.) Kuetz. and *Myriophyllum triphyllum* Orchard included the green algae *Stichococcus bacillaris, Schizomeris leibleinii* (illustrated by Cassie 1983), *Oedogonium* and *Spirogyra* spp. and the tiny pennate diatom *Amphora perpusilla*. Also common were the desmids *Gonatozygon aculeatum* and *G. kinahanii* (illustrated by Croasdale & Flint 1986).

After 1982, the Lake Pupuke Management Committee organised the removal of large quantities of rafted lakeweed. As a consequence there appears to have been a noticeable reduction in the prevalence of inshore micro-algae.

From 1976 to 1984, *Cladophora glomerata* formed a pale grass-green border at the air-water interface of basalt rocks fringing the lake, especially at Sylvan Park and near the hospital. Apparently the community has since declined; and it had disappeared altogether in many places by 1987. In places where a healthy growth used to occur, its gelatinous branchlets acted as host to colonies of pennate diatoms, including stalked *Gomphoneis herculeana, Rhoicosphenia curvata*, sessile *Epithemia sorex* and *Amphora perpusilla*. This community had virtually disappeared by May 1987.

EPILITHON AND EPIPELON

An assemblage of pollution-tolerant species on hard basalt rock surfaces in the path of the outflow from the large hospital stormwater drain persisted from 1976 to 1982. It included the *Stigeoclonium* stage of *Schizomeris*, and the diatoms *Gomphonema parvulum* (see Cassie 1983), *Nitzchia obtusa, N. linearis, Nitzschia* spp. cf. *pilum* and palea and *Navicula cuspidata*.

LAGOON, SMALE'S QUARRY

Lagarosiphon major is the dominant macrophyte in the inshore shallows of this enclosed backwater of Lake Pupuke. While the algal population does not vary markedly from that in the main lake, there is a difference in ecological balance, which has possibly affected the different physio-chemical characteristics of this water body; e.g., pH, oxygen, carbon dioxide and temperature regimens (F.I. Dromgoole, pers. comm.). Prominent phytoplankters included the euglenoid flagellates *Trachelomonas volvocina* and *T. sydneyensis* (see Cassie 1983), slender filaments of the centric diatom *Aulacosira* (=*Melosira*) *granulata* var. *angustissima*, (a variety which is not genetically distinct from *A. granulata* - Kilham & Kilham 1975), and oval, 8-celled colonies of *Nephrocytium agardhianum*.

A dense green carpet formed by two *Spirogyra* species clothed the grassy sward and shallows of the lagoon in winter. The compact, densely intertwined weft of these filaments supported a rich community of large living diatom cells with prominent yellow-brown chloroplasts (*Nitzschia linearis, Navicula radiosa, Fragilaria crotonensis*), blue-green filaments of *Anabaena oscillarioides*, and many colourless (protozoan?) flagellates.

DISCUSSION

Planktonic algae reported in earlier works included *Anabaena circinalis* (dominant in 1966-67), *Closterium aciculare, Staurastrum muticum, Staurastrum* spp., *Melosira granulata* and *Ceratium hirundinella* (Barker unpublished 1967). Green (1967) identified *Closterium aciculare, Staurastrum* spp. and *Ceratium hirundinella*, and made estimates of winter phytoplankton at different depths. L. Ronberg (ARWB 1983) recorded *Gonium* sp., *Gloeocystis* sp., *Elakatothrix* sp., and *Chroomonas minuta* in addition to those identified in this survey, in the mid-lake phytoplankton. A bloom of *Botryococcus braunii* was recorded by her in November 1981. *Ana-*

baena circinalis, Gloeocystis and *Gonium* were not found during the present survey. However after 22 years, *Anabaena* re-appeared as a dominant in the top 2 m in cell counts by L. Ronberg during February, 1988 (E.T. Grogan, pers. comm.).

The winter phytoplankton of Lake Pupuke bears a general resemblance to that in Category 8 of Reynolds (1980), in which the chief dominants are species of *Melosira, Fragilaria* and *Closterium*, with associated *Microcystis, Ceratium, Closterium, Staurastrum* and cryptomonads. Such an assemblage occurs with stable thermal conditions, an abundance of free available nutrients (including iron, silica, and nitrogen), high growth rates, and vegetative stocks which can survive unfavourable periods on the sediments (such as *Aulacosira granulata*).

Summer dominance of *Microcystis* indicates an affinity with Reynolds' Category 9, where stratification and hypolimnetic anoxia prevail, day-length is long and temperatures are above 14°C. Growth rates of *Microcystis* are controlled by nitrogen and phosphorus. When *Microcystis* is preceded by, or co-dominates with *Peridinium* spp., phosphorus is the chief limiting factor; and the summer phytoplankton situation is comparable to that in Lake Kinnaret, Israel, where *Microcystis* blooms are frequently preceded by *Peridinium cinctum* f. *westii* (Lemm.), and where autumn production is usually limited by shortage of phosphorus (Serruya & Pollingher 1971).

Over the last 20 years at Lake Pupuke, winter dominance in the phytoplankton by desmids *(Closterium aciculare, Staurastrum* spp.), and dinoflagellates (mainly *Ceratium hirundinella*) has remained fairly consistent. *Closterium aciculare* is widespread elsewhere in New Zealand lakes (Craosdale & Flint 1986). *Ceratium hirundinella* is probably responsible for the characteristically fishy odour of Lake Pupuke in winter (Green 1967, Barker 1970), and *Peridinium* spp. in summer.

Compound indices of 2.0 for phytoplankton, 2.2 for periphyton and 2.5 for all taxa, indicate that the lake is moderately eutrophic - a conclusion also reached by Coffey & Clayton (1987) from macrophyte evidence. Taxa tolerating a high degree of organic pollution were few in number, and were intimately associated either with swan excreta or with overflow discharges from drains and pumping stations.

Mid-lake surface water quality is regarded by D. Challis (A.R.W.B. 1983), as fairly high (i.e. high dissolved oxygen values, low non-filterable residue, low biochemical oxygen demand, low nitrogen and phosphorus values and low bacterial counts). From 1977 to 1982 there did not appear to be any significant increase in phytoplankton populations. Figure 2 of the 1977-1982 survey demonstrates that cell counts are dramatically reduced below 20 m in all seasons. Additional evidence in support of low cell numbers and anoxic conditions in the hypolimnion at certain times comes from unpublished investigations by freshwater ecology students of the Botany and Zoology Departments, The University of Auckland (F.I. Dromgoole, pers. comm.). Both Barker (1967) and Green (1967) stressed that there could be adverse effects on the biota, particularly at and near the bottom, of high sulfide values. Barker (1970) recorded values of up to 2.0 ppm in the marginal waters of the lake down to 6 m, and suggested that lower values in the main body of the lake were correlated with absence or scarcity of *Ceratium hirundinella*. A maximum of 3-4 ppm at the bottom was recorded by the Auckland Regional Authority between 1975 and 1982 (ARWB 1983). There is obviously a need for a more detailed study of this factor in other parts of the lake and in the sediments.

Pollution-tolerant diatoms identified included species able to survive a saprobity of 4 or 5 (alpha-mesosaprobic, polysaprobic; Lowe 1974). Many diatoms have a wide range of tolerance to saprobic conditions; e.g. *Nitzschia palea* can tolerate oligosaprobic as well as polysaprobic habitats. Lange-Bertalot (1978) has stressed that it is the upper limit of pollution-tolerance rather than the actual saprobic conditions which determines whether a diatom species can survive. Other factors such as pH, salt tolerance, substrate, metabolism and nutrient requirements will also have a determining effect on diatom presence or absence.

Three potentially toxic blue-green algae were recorded: *Microcystis aeruginosa* and *Coelosphaerium kuetzingianum* in the phytoplankton, and *Anabaena flos-aquae* in the metaphyton. *Microcystis* has bloomed in all summers since 1976. In the summer of 1982, corpses of several cygnets were removed from the lake shore by concerned residents. Although the cause of their deaths is not known for certain, it is conceivable that they could have been due, at least in part, to microcystin - a toxin which can kill a mouse in 15-20 minutes. *Anabaena flos-aquae* can liberate an even more potent toxin, lethal to mice in 1-2 minutes (see review in Cassie 1979).

To summarise, it appears that algal populations in both phytoplankton and phytobenthos have remained fairly stable or become smaller since the removal of large quantities of floating macrophytes, and hence of large quantities of nutrients. Another factor limiting micro-algal growth, as yet not clearly defined, could be the presence of a toxic chemical or chemicals, e.g. excess hydrogen sulfide, or some substance entering the lake ecosystem from the hospital or other drains.

If the water quality of Lake Pupuke is to be maintained at a level which is adequate for use as an emergency water supply, it will be necessary to make more frequent detailed and comprehensive observations of its chemical and biological parameters; and to monitor the algae of the phytoplankton, metaphyton, epipelon and epilithon more closely in order to observe any long-term trends.

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Appendix I. *(On following pages.)* Algae identified from Lake Pupuke. Identifications of micro-algae after Fott (1968), Bourrelly (1972, 1981, 1985), Růžička (1977, 1981), Prescott (1982), Forster (1982), and Komárek & Fott (1983). Abundance scale (after Cassie (1961): 5 = dominant; 4 = abundant; 3 = common; 2 = occasional; 1 = scarce; - = absent. Community (after Round 1981): Ph = phytoplankton; M = epiphyton; Ep = epilithon, epipelon. Saprobity (after Lowe 1974, and VanLandingham 1982): 5 = polysaprobic; 4 = alpha-mesosaprobic; 3 = beta-mesosaprobic; 2 = oligosaprobic; 1 = saproxenous; ? = rating uncertain. Toxicity: T = toxic.

APPENDIX I

ALGAE	Saprobity	Community	Pumphouse	Sylvan Park	Shakespeare Rd	Hospital	Lagoon	Inshore phytoplankton	Mid-lake phytoplankton	Date of maximum numbers	Collection reference	Remarks
CHLOROPHYCEAE												
VOLVOCALES												
Chlamydomonas sp.	3	Ph	5	3	-	-	-	-	-	5-4-78	Culture	
										3-11-81	Herb. 2531	
CHLOROCOCCALES												
Actinastrum gracillimum G..M. Smith	2-3	Ph	-	-	-	-	-	-	1	26-9-76	Fig. V.C. coll.	Spring
Botryococcus braunii Kuetzing	2	Ph	-	-	-	-	-	-	>5	1-5-87	Herb. 3270	
Chodatella ciliata (Lagerh.) Lemm.	2	Ph	-	-	-	2	2	-		1-9-76	Herb. 2011	
Chodatella citriformis (Snow) C.M. Smith	2	Ph	2	-	-	-	-	-	2	3-4-76	Herb. 64	Autumn
										1-9-76	Herb. 2011	
									2	17-6-80		Winter
Kermatia pupukensis Kal. et Puncoch.	3	Ph	-	-	-	5	5	-	-	29-4-77		Autumn
(non *Chlorella minutissima* Fott et Nováková)										17-6-80	Herb. 2528	Winter
Chlorella sp.	-	Ph	5	5	-	-	-	-	-	19-2-82	Fig. V.C. coll.	Summer
Coelastrum microporum Naegeli	1-2	M	-	-	-	-	1	-	-	19-2-82	Herb. 2671	Late summer
Nephrocytium agardhianum Naegeli	1-2	Ph	-	-	-	-	2	2	-	29-4-77	Fig. V.C. coll.	Autumn
Oocystis marssonii Lemmermann	2-3	Ph	-	-	-	-	-	-	2	26-9-76	Fig. V.C. coll.	Spring
Westella botryoides (W. West) de Wilde	1-2	Ph	-	-	-	3	-	3	-	17-11-82	Fig. V.C. coll.	Early summer
ULOTHRICOPHYCEAE												
ULOTHRICALES												
Schizomeris leibleinii Kuetzing	3-4	E	-	-	5	-	5	-	-	28-2-78	Fig. V.C. coll.	Late summer
Stichococcus bacillaris Naegeli	3	M	-	-	-	2	2	-	-	25-3-77	Fig. V.C. coll.	Absent by 1987
Ulothrix cylindricum Prescott	2	M	-	-	1	-	-	-	-	4-2-76	Herb. 43	Declined by 1987
SIPHONOCLADALES												
Cladophora glomerata (Linn.) Kuetzing	3	Ep	5	5	-	5	-	-	-	5-11-82	Herb. 35	All seasons. Declined by 1987
CHAETOPHORALES												
Coleochaete irregularis Pringsheim	?	E	-	-	-	2	-	-	-	17-6-80	Herb. 2527	Winter
Coleochaete orbicularis Pringsheim	?	E	-	-	3	5	-	-	-	4-7-83	Fig. V.C. coll.	Winter, on rotting *Vallisneria*
Stigeoclonium tenue (Agardh) Kuetzing	4-5	Ep	-	-	-	5	-	-	-	17-6-80	Herb. 2529	Winter
OEDOGONIALES												
Oedogonium sp. cf *amplum*	3-4	Pe	5	5	5	-	4	-	-	1-11-82	Herb. 4b,53	Spring-summer (swan excreta). Oospores, Febuary 1976
ZYGOPHYCEAE												
ZYGENEMATALES												
Actinotaenium globosum (Bulnh.) Krieg. et Gerl.	2-3	Ph	-	-	-	-	2	-	-	11-11-82	L.M. photo 713	Early summer
Closterium aciculare T. West	2-3	Ph	-	-	5	5	3	5	5	4-7-83	Herb 59	Winter
Closterium acutum var. *variabile* (Lemm.) Krieger	2-3	Ph	1	-	-	-	-	2	-	7-6-86	Fig. V.C. coll.	Winter
Closterium sp.	?	M	1	-	-	-	-	-	-	23-2-82	Fig. V.C. coll.	Late summer
Cosmarium sp. cf *phaseolus*	?	Ph	-	-	-	-	2	-	-	28-6-77	Fig. V.C. coll.	Winter
Cosmarium sp. cf *sexangulare*	?	Ph	1	-	-	-	-	-	-	1-11-82	Fig. V.C. coll.	Spring
Gonatozygon aculeatum Hastings	2-3	M	-	-	-	1	-	-	-	3-4-76	Fig. V.C. coll.	Autumn

Appendix I. *(Continued from previous page.)*

ALGAE	Saprobity	Community	Pumphouse	Sylvan Park	Shakespeare Rd	Hospital	Lagoon	Inshore phytoplankton	Mid-lake phytoplankton	Date of maximum numbers	Collection reference	Remarks
Gonatozygon brebissonii var. *minutum* (W. West) West et West	2-3	Ph	-	-	-	-	1	-	-	10-11-76	Fig. V.C. coll.	Early summer
Gonatozygon kinihanii (Archer) Rabenh.	2-3	M	-	1	-	1	-	-	-	13-12-76	Fig. V.C. coll.	Summer
Mougeotia sp.	2-3	M	3	-	-	2	2	2	2	17-6-80	Herb. 2532	Winter
Spirogyra sp. (large cells)	?	M	3	-	-	-	5	-	-	17-6-80	Herb. 2532	
Spirogyra sp. (small cells)		?	M	-	-	-	-	5	-	-	29-6-80	Fig. V.C. coll.
Staurastrum sp. cf chaetoceras	2-3	Ph	2	-	-	2	-	-	2	23-9-76	Fig. V.C. coll.	Spring
Staurastrum johnsonii var. *altius* Fritsch et Rich	2-3	Ph	-	-	-	2	-	-	3	26-9-76	Fig. V.C. coll.	Spring
Staurastrum pingue Teiling	2-3	Ph	-	-	-	2	1	2	3	24-9-76	Fig. V.C. coll.	Spring
Staurastrum smithii (G.M. Smith) Teiling	2-3	Ph	-	-	-	-	2	-	3	11-11-82	Fig. V.C. coll.	Spring
CHRYSOPHYCEAE												
CHROMULINALES												
Chrysamoeba sp. cf *radicans*	?	Ph	-	-	2	-	-	2	-	29-4-77	Fig. V.C. coll.	Autumn
OCHROMONADALES												
Synura sp.	?	Ph	-	-	2	-	-	2	-	23-1-76	Herb. 39	Summer
MONOSIGALES												
Salpingoeca sp. (on *Spirogyra*)	2-3	E	-	2	-	-	-	-	-	7-6-76	Herb. 92	Winter
XANTHOPHYCEAE												
RHIZOCHLORIDALES												
Stipitococcus sp. (on *Schizomeris*)	3-4	E	2	-	-	-	-	-	-	26-8-83	Herb. 2883	Winter-spring
DIATOMOPHYCEAE/BACILLARIOPHYCEAE												
CENTRALES												
Aulacosira (=*Melosira*) *granulata* (Ehrenberg) Simonsen	2-4	Ph	1	-	-	4	-	5	5	11-5-87	Herb. 3270	
Aulacosira (=*Melosira*) *granulata* var. *angustissima* O. Mueller	2-4	Ph	-	-	-	-	-	5	-	4-7-83	Fig. V.C. coll.	Winter-spring
Melosira varians Agardh	1-2	E,Ep	-	-	-	1	-	-	-	4-7-83	Fig. V.C. coll.	Winter-spring
PENNALES												
Achnanthes brevipes var. *parvula* (Kuetz.) Cleve (on *Cladophora*)	?	E	-	-	2	-	-	-	-	5-11-82	Fig. V.C. coll.	Early summer
Amphora perpusilla Grunow	?	E,Ep	1	-	-	1	2	-	-	23-2-82	Fig. V.C. coll.	Late summer
Cocconeis placentula var. *lineata* (Ehrenberg) Van Heurck (on *Vallisneria*)	2-3	E	3	-	-	5	4	-	-	19-2-82	Herb. 2532	Late summer
Cocconeis placentula var. *euglypta* (Ehrenberg) Cleve (on *Vallisneria*)	2-3	E	3	-	5	5	4	-	-	19-2-82	Herb. 2532	Late summer
Epithemia sorex Kuetzing (on *Vallisneria*)	3-4	E, Ep	-	-	5	5	3	-	-	29-4-77	Fig. V.C. coll.	Autumn
Epithemia zebra (Ehrenberg) Kuetzing (on *Vallisneria*)	1-2	E	-	-	-	5	-	-	-	4-2-76	Fig. V.C. coll.	Late autumn
Fragilaria crotonensis Kitton	2-4	Ph	-	-	-	5	-	-	-	10-11-76	Herb. 2035	
Frustulia rhomboides var. *saxonica* (Rabenhorst) De Toni	1	E,Ep	-	1	-	-	-	-	-	27-8-83	Fig. V.C. coll.	Spring
Gomphoneis herculeana (Ehrbg) Cleve	?	E	3	-	-	-	4	-	-	17-6-80	Fig. V.C. coll.	
Gomphonema parvulum (Kuetz.) Kuetz.	3-5	E,Ep	-	-	-	1	-	-	-	29-4-77	Fig. V.C. coll.	Autumn
Hantzschia amphioxys (Ehrbg.) Grun.	3-4	E,Ep	-	-	-	1	-	-	-	29-4-77	Fig. V.C. coll.	Autumn
Navicula cuspidata (Kuetzing) Kuetzing	2-4	E,Ep	-	-	2	-	-	-	-	3-11-81	Herb. 2531 TEM 625	
Navicula elginensis var. *neglecta* (Krasske) Patrick	?	E,Ep	-	-	-	5	-	-	-	29-4-77	Slide 398	
Navicula sp. cf *frugalis*	1-3	E,Ep	-	-	1	-	-	-	-	3-11-81	Herb. 2531 TEM 635	Summer-autumn

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ALGAE	Saprobity	Community	Pumphouse	Sylvan Park	Shakespeare Rd	Hospital	Lagoon	Inshore phytoplankton	Mid-lake phytoplankton	Date of maximum numbers	Collection reference	Remarks
Navicula radiosa Kuetzing	2-3	E,Ep	5	-	-	-	4	-	-	23-2-82	Fig. V.C. coll.	
Nitzschia acicularis (Kuetz.) W. Smith	2-4	Ph,M	-	-	-	1	2	-	-	4-7-83	Herb. 2671	Winter
Nitzschia linearis (Agardh) W. Smith	2	E,Ep	-	-	-	3	4	-	-	4-7-83	Herb. 2671	Winter
Nitzschia obtusa W. Smith	?	E	-	-	-	5	-	-	-	29-4-78	Herb. 58	Autumn
Nitzschia sp. cf *pilum*	3-5	E,Ep	5	-	-	-	3	-	-	29-2-76	Fig. V.C. coll.	Late summer
Nitzschia sp.	2-3	E,Ep	5	-	-	-	3	-	-	17-6-80	Fig. V.C. coll.	Winter
Rhoicosphenia curvata (Kuetzing) Grun.	2-4	E	-	3	-	-	-	-	-	5-11-82 11-11-82	Fig. V.C. coll. Herb. 2532	
Rhopalodia gibba (Ehrbg.) O. Mueller	2-4	E,Ep	-	3	5	-	3	-	-	29-2-76	Herb. 58 Slide 36	
Surirella sp. cf *ovalis*	?	E	-	-	2	-	2	-	-	5-4-78	Fig. V.C. coll.	
Surirella delicatissima Lewis	?	E	-	-	-	2	-	-	-	23-9-76	Fig. V.C. coll.	
Synedra ulna (Nitzsch) Ehrbg. (among filamentous algae and *Vallisneria*)	2-3	M	3	-	-	2	-	2	-	3-11-81	TEM 638	
CRYPTOPHYCEAE												
CRYPTOMONADALES												
Chroomonas minuta (Skuja) Bourrelly (=*Rhodomonas minuta* Skuja)	?	Ph	-	-	-	-	-	-	2	3-11-81	TEM 638	
Cryptomonas erosa Ehrenberg	3-5	Ph	2	-	-	-	-	-	-	17-11-82	Fig. V.C. coll.	
DINOPHYCEAE												
PERIDINIALES												
Ceratium hirundinella f. *furcoides* Schroeder	2-3	Ph	-	3	-	1	-	-	5	11-5-87	Herb. 3270	
Cystodinium sp. cf *closterium*	?	M	-	1	-	-	-	-	-	17-6-80	Herb. 2531	
Peridinium volzii Lemmermann	2-3?	Ph	-	3 cysts	2	5	-	5	5	4-2-76	Fig. V.C. coll.	
Peridinium willei Huitfeldt-Kaas	2-3?	Ph	3	3	5	-	-	-	5	4-2-76	Fig. V.C. coll.	
EUGLENOPHYCEAE												
EUGLENALES												
Euglena sp. cf *polymorpha*	3-5	M	-	3	5	-	-	5	-	2-9-76 5-4-78	Herb. 67 Fig. V.C. coll.	
Euglena sp. cf *proxima*	3-5	M	-	-	-	2	-	-	-	19-2-82	Herb. 2671	
Trachelomonas sydneyensis Playfair	2-4	Ph	-	-	-	2	5	-	-	19-2-82	Herb. 2671	
Trachelomonas volvocina Ehrenberg	2-4	Ph	-	-	-	-	2	-	-	19-2-82	Herb. 2671	
Urceolus sp. cf *cyclostomatus*	?	E	-	-	-	1	-	-	-	13-5-83	Fig. V.C. coll.	
Unidentified protozoon flagellates	?	Ph,M	5	5	5	5	3	5	-	1-2-76	Herb. 43	
CYANOPHYCEAE												
CHROOCOCALLES												
Coelosphaerium kuetzingianum Naegeli	2(T)	Ph	-	-	1	-	-	-	-	4-2-76	Fig. V.C. coll.	
Merismopedia tenuissima Lemmermann	?	M	-	-	1	-	3	3	-	28-3-84	Fig. V.C. coll.	
Microcystis aeruginosa Kuetzing	1-4	Ph	-	-	1	5	2	5	5	29-3-77	Herb. 2058	
NOSTOCALES												
Anabaena aphanizomenoides Forti	?	Ph	-	-	-	-	-	-	5	26-4-77	Fig. V.C. coll.	Culture
Anabaena flos-aquae (Lyngb.) Breb. (on *Coleochaete*)	1(T)	M	-	-	2	-	-	-	-	2-3-78	Fig. V.C. coll.	
Anabaena oscillarioides Bory	?	Ph	-	-	-	2	2	-	-	17-6-80	Herb. 2529	
Anabaenopsis sp.	1-4?	M	-	-	-	-	2	-	-	19-2-82	Herb. 2671	
Gloeotrichia sp.	?	M,Ph	-	-	-	2	-	-	-	26-4-77	Herb. 2069	Culture
Nodularia harveyana var. *sphaerocarpa* Skuja	?	M	-	-	-	-	1	-	-	26-4-77	Fig. V.C. coll.	

Appendix I. *(Continued from previous page.)*

ALGAE	Saprobity	Community	Pumphouse	Sylvan Park	Shakespeare Rd	Hospital	Lagoon	Inshore phytoplankton	Mid-lake phytoplankton	Date of maximum numbers	Collection reference	Remarks
Oscillatoria limosa Agardh	0-5	M,Ep	-	-	-	4	-	-	-	29-2-76	Herb. 55	
Oscillatoria princeps Vaucher										11-5-87	Fig. V.C. coll.	
Oscillatoria subbrevis Schmidle	3-5?	M,Ep	-	-	-	-	3	-	-	28-4-77	Fig. V.C. coll.	
Oscillatoria tenuis Agardh	1-5	Ph,M	5	5	5	5	5	-	-	11-1-82	Fig. V.C. coll.	
Oscillatoria subgenus *Spirulina*												
Spirulina gigantea Schmidle	3-5?	Ph,M	-	-	-	5	-	-	-	28-4-77	Fig. V.C. coll.	
Spirulina labyrinthiformis (Mengh.)	2-5?	Ph,M	-	-	-	-	5	-	-	5-4-78	Fig. V.C. coll.	
Spirulina major Kuetzing	3-5?	Ph,M	-	-	-	-	5	-	-	4-7-83	Fig. V.C. coll.	

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